MEMORANDUM

To:

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Subject : On-Farm Irrigation Systems Management

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The following technical memorandum has been prepared to support the analysis for the Programmatic Environmental Impact Statement being prepared by the Bureau of Reclamation, Mid-Pacific Region, as required under Public Law 102-575, Title 34, Central Valley Project Improvement Act (CVPIA).

The information compiled on irrigation system costs and performance draws substantially on previous work completed by CH2M HILL for the San Luis Unit Drainage Program of the Bureau of Reclamation. Modifications include additions of solid-set sprinkler systems and rice irrigation methods, and expansion of total irrigation cost estimates to the entire Central Valley as organized under Sacramento Valley, Delta, and San Joaquin Valley regions. All categories of cost were reexamined and a number of revisions have been incorporated. To avoid duplicative work and to facilitate review by those already familiar with the information, the original report format has been retained. Notes provided to the reader will assist in determination of sections that have not been modified.

These costs and performance characterizations will be used to assess changes in irrigation practices that may result due to implementation of the CVPIA.

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Section 1
Introduction

Title 34 requires that the Secretary of the Interior prepare a Programmatic EIS analyzing the direct and indirect impacts and benefits of Title 34, Central Valley Project Improvement Act, including all fish, wildlife, and habitat restoration actions and the potential renewal of all existing CVP water contracts. The PEIS focuses on systemwide actions examining the broad environmental implications of government policy decisions. Modeling will play a significant role in determining these implications. One portion of the modeling effort will focus on the economic impact to the agricultural sector through the use of CVPM (Central Valley Production Model).

The CVPM was originally developed by the Department of Water Resources (DWR) for internal uses in analyzing policy changes of the State Water Project. Working in conjunction with DWR, CVPM is being adapted for use in analyzing the potential impacts and benefits of the Act. System costs and hydraulic performance characteristics presented in this study will be utilized as input to the model. Included are irrigation systems commonly found in the study area as well as those that are used infrequently or not found at present but compare favorably with existing systems in terms of increasing on-farm irrigation efficiencies. This latter category is referred to as emerging technologies.

Because irrigation system performance and cost are related to management, as well as physical components and configuration, three management levels are delineated. These relatively subjective levels are defined as follows:

- Low Management Level--Minimum management effort, characterized by philosophies and activities often found in areas where irrigation water is inexpensive.

- Medium Management Level--Typical management effort found in the districts where water is relatively expensive and water conservation programs have been active for many years.

- High Management Level--Management effort required to obtain near maximum potential irrigation efficiency for each given method.

Limited field trial data is available for many of the combinations of systems, crops, and management levels investigated. Consequently, this study relies substantially on information provided by farmers, irrigation equipment vendors, and irrigation scheduling consultants, plus engineering judgment and experience. Data sources are listed in Appendixes A and B. Key assumptions made to facilitate this analysis are noted in this report.

1.1 Regional Categories

This report has been broadened from the original western San Joaquin Valley study area (Gohring, 1991) to incorporate the entire Central Valley of California. The cost and performance methodology can be generalized to any region for which the included crops and irrigation systems are appropriate. This report shows results for three regions: Sacramento Valley, approximately the City of Sacramento northward; Delta Region, inclusive of Solano County, portion of Sacramento County, San Joaquin County, and Contra Costa County; and San Joaquin Valley, inclusive of Stanislaus County southward to Kern County. Regional differences are incorporated by modifying the evapotranspiration rates of applied water (ETAW). Not all tables or evaluation factors are impacted by regional variations in ET and therefore are presented generically for all regions. These include: distribution fractions, component costs for the various irrigation technologies, annual capital and maintenance costs, unit labor requirements for irrigation systems, and irrigation administration costs. The factors presented above are discussed in further detail elsewhere in this study.

Section 2
Irrigation Systems

Irrigation systems in the Central Valley are as varied as the people who use them. Because of the multitude of irrigation products on the market and the innovative and resourceful nature of farmers, an infinite number of irrigation systems are in operation today, 14 of which have been selected for inclusion for this report (Table 2.1). Solid Set sprinklers along with three irrigation methods for rice have been added to the original technical memorandum (Gohring, 1991).

Surface irrigation methods remain the most widely used in the Central Valley. Systems chosen to represent this category are half-mile furrows with and without tailwater return, quarter-mile furrows with and without tailwater return, and border strips with and without tailwater return. Surge-controlled furrows with tailwater return on half- and quarter-mile runs represent emerging surface technologies.

Methods for irrigating rice fields have been added to this study to account for the rice production in the Sacramento Valley and, to a limited extent, in other regions. Methods chosen for this category include: conventional flow-through systems, recirculating systems, and static systems. The static system represents an emerging technology.

Sprinkler irrigation is represented by three systems: hand-move sprinklers, which are fairly common; solid set sprinklers, used for many permanent tree and vine crops; and linear-move sprinklers. A Low Energy Precision Application (LEPA) system, which replaces sprinkler heads on a linear-move system with drop tubes and bubblers, is also included as an emerging technology.

Finally, surface drip irrigation represents the most common form of drip irrigation method, while subsurface drip irrigation is included as an emerging technology.

Any irrigation system can be operated with varying degrees of management. In some cases, however, it is most practical to assume that upgrading of the type of system used is inevitable as the management level of certain irrigation methods increases. Systems used for low levels of management are typically very simple and often represent the minimum capital investment required to implement that irrigation method. Therefore, to reduce the total combination of irrigation systems evaluated, five irrigation systems were restricted to only two levels of management (Table 2.1). Half-mile furrow systems were not evaluated under high management levels, and conversely, half- and quarter-mile furrows with return systems and surge furrow systems were not evaluated under low management. The belief is that a person willing to make the capital investment to allow for better control of water during irrigation events will most likely place more effort into managing the system to a higher degree.

Table 2.1
Irrigation Methods

Abbreviation	Description of Method	Management Level	Description of System
F1-2	Half-mile furrows	Low Medium High	Siphon tubes Gated pipe Gated pipe
F1-2R	Half-mile furrows with tailwater return	Low Medium High	Siphon tubes Gated pipe Gated pipe
F1-4	Quarter-mile furrows	Low Medium High	Siphon tubes Gated pipe Gated pipe
F1-4R	Quarter-mile furrows with tailwater return	Low Medium High	Siphon tubes Gated pipe Gated pipe
BORD	Border strip	Low Medium High	Siphon tubes (1/2-mile runs) Pipeline with alfalfa valves (1/4-mile runs) Pipeline with alfalfa valves (1/4-mile runs)
BORD-R	Border strip with tailwater return	Low Medium High	Siphon tubes (1/2-mile runs) Pipeline with alfalfa valves (1/4-mile runs) Pipeline with alfalfa valves (1/4-mile runs)
RICE-C	Rice irrigation systems	Flow-through Recirculating Static	Series of dropping checks Use of tailwater returns Closed basins
SURG-2	Surge-controlled half-mile furrows with tailwater return	Low Medium High	Gated pipe with surge valve Gated pipe with surge valve Gated pipe with surge valve
SURG-4	Surge-controlled quarter-mile furrows with tailwater return	Low Medium High	Gated pipe with surge valve Gated pipe with surge valve Gated pipe with surge valve
HMS	Hand-move sprinklers	Low Medium High	4-inch x 30-foot laterals 4-inch x 30-foot laterals 4-inch x 30-foot laterals
DRIP	Surface drip	Low Medium High	Turnkey type system Turnkey type system Turnkey type system
S-DRIP	Subsurface drip	Low Medium High	Turnkey type system Turnkey type system Turnkey type system
LINEAR	Linear-move sprinklers	Low Medium High	1/2-mile linear system 1/2-mile linear system 1/2-mile linear system
LEPA	Low Energy Precision Application with linear-move system	Low Medium High	1/2-mile linear system 1/2-mile linear system 1/2-mile linear system
SOLID SET	Solid-set sprinklers	Low Medium High	Turnkey type system Turnkey type system Turnkey type system

Costs and hydraulic performance characterizations are based on a conceptual design of each of the systems listed in Table 2.1. Each conceptual design includes the major system components required to irrigate a representative parcel assuming water is delivered to the high corner of the parcel under approximately 5 feet of head (Johnson, 1987). The representative parcel for all of the methods except the linear-move sprinkler and LEPA systems is a 160-acre square field or typical quarter-section parcel. The conceptual design for the linear-move sprinklers and LEPA system is based on a half- section (320-acre) system.

Each representative system is described below. Components of each system, including pipe size, are tabulated in the Capital Costs section of this report.

2.1 Furrow Systems

Furrow irrigation is used extensively on a wide variety of crops in the Central Valley. For half-mile furrows under low management levels, the representative system consists of a single earth-lined head ditch and small-diameter siphon tubes to deliver water to the furrows. To benefit from medium and high levels of management, a single line of gated pipe replaces the head ditch.

For the quarter-mile furrows under low management, the representative system consists of an unlined head ditch at the top of the field and a second ditch running along the side and across the center of the field, resulting in approximately 1.25 miles of head ditch. Siphon tubes deliver water from these head ditches to the furrows.

For medium and high management levels, the head ditches are replaced with pipe: gated pipe across the head and center of the field, and plain pipe along the side. The quarter-mile gated pipe system includes additional appurtenances such as valves and fittings.

The same tailwater return system is assumed to be used for both the quarter- and half-mile furrow systems (see Section 2.10).

2.2 Border Strip Systems

Border strip irrigation is used extensively on hay and grain crops and on trees and vines in the Central Valley. The irrigation system generally consists of a head ditch or pipeline to deliver water to the field and a series of borders or ridges that guide a moving sheet of water down strips, typically 20 to 60 feet wide.

For the low level of management, the system configuration consists of half-mile runs. Quarter-mile runs are used for the medium and high management levels. For low levels of management, it is assumed that the water delivery system will consist of an unlined head ditch and large-diameter siphon tubes. For medium and high levels of management, it is assumed that the delivery system will consist of a buried plastic pipeline with alfalfa valves.

It is assumed that these systems can be used with the tailwater recovery system described in Section 2.10.

2.3 Rice Systems

Rice is extensively grown in the Sacramento Valley with limited production in the Delta and San Joaquin regions. Irrigation systems usually consist of large basins where the rice is grown and into which water is flooded. Three variations of rice irrigation are presented here.

Flow-through systems are the most common. This system allows water to flood into the first field of a series of fields, then water flows through check structures into each subsequent field (basin). At the last field, the water typically flows into a drain and leaves the property. Modifications to this basic system have led to the use of recirculating and static systems. Recirculating systems are similar to tailwater recovery systems (discussed below). A collection ditch at the last field allows water to be captured and pumped either to the head of the same field or to another field in the vicinity.

The static system is an emerging technology. This system allows water to flow into each field as needed to keep water levels optimum; however, water can only drain through the same inlet pipe which it entered. A supply ditch with regulating weirs for each field controls the water level in the basin.

Rice irrigation systems are not broken into management levels because rice growers closely manage their water already. Water management is one of the key elements to successful rice production. The three rice systems differ only slightly in consumptive use fractions due to common losses from evaporation, deep percolation (soil type is similar for most fields), and need to drain fields prior to harvest. A small difference in spillage losses differentiates the systems.

2.4 Surge Control Furrow Systems

Surge control consists of intermittent delivery, or cycling, of water flow into furrows, compared to continuous flow for the full irrigation time used in standard furrow irrigation. The effect of surging is that the advance time, or the time required for flows to reach the end of the furrows, is reduced. The result is a smaller difference between infiltration opportunity times at the head and tail ends of the furrows and, consequently, more uniform application of water compared to standard furrows.

Surge flow cycling can be achieved by manual operation of control valves, gates, or siphon tubes; however, automated control using a prefabricated surge valve appears to be the most practical means of control. Because surge control furrows represent an advanced technology, only medium and high management levels, incorporating automated control and return flow systems, are considered.

The half-mile surge control system includes a quarter-mile of carry pipe that conveys the water to the center of the head of the field and a surge valve that alternates the flow of water to the two quarter-mile sections of gated pipe that run across the head of the field. The surge valve assumed is a generic representation of a few model types currently available on the market. The valve uses either batteries or a small solar collector to power a microprocessor and the butterfly actuator. The microprocessor can be programmed to alternate the flow according to different schedules.

The quarter-mile surge control system uses the surge valve near the irrigation turnout to alternate the flow between the upper and lower ends of the field. This layout requires a quarter-mile of carry pipe along the side of the field and two half-mile lengths of gated pipe along the head and center of the field.

2.5 Hand-move Sprinkler Systems

Hand-move sprinklers are commonly used throughout the Central Valley on cotton, alfalfa, row crops, small grains and other crops. The system used to represent hand-move sprinklers is a typical quarter-section layout. The layout incorporates a booster pump near the irrigation turnout, an aluminum above-ground mainline that runs along half the length of one side and across the center of the square field, and portable aluminum sprinkler laterals.

With a total lateral length of 1/4 mile, 4-inch-diameter laterals are required to avoid high friction loss and obtain satisfactory pressure uniformity. The sprinkler spacing used is 50 feet along the mainline and 30 feet along the lateral. There are six laterals on each side of the mainline at any one time.

The sprinklers and risers assumed are those typically used on cotton installations. The booster pump used in the system has a discharge flow rate of 1,600 gallons per minute (gpm) at 80 pounds per square inch (psi) pressure at the pump discharge. Low pressure sprinkler nozzles were not included for any management level, because use of these devices has not shown a net economic advantage (Gohring and Wallender, 1987).

2.6 Surface and Subsurface Drip Systems

Drip irrigation systems are used on a limited scale in the Central Valley, primarily on permanent tree and vine crops, although increased use of surface and subsurface drip systems on row and vegetable crops is occurring. Field trials are beginning to show a potential economic advantage over other conventional methods (Fulton et. al., 1991, Phene et at., 1993, U.C. Extension Service, Imperial County, 1993). For surface and subsurface drip irrigation methods, a single irrigation system was chosen to represent the three levels of management, because drip systems are often installed as turnkey systems.

The characteristic drip system consists of a booster pump, filtration station, buried mainline and submains, and lateral distribution lines. The booster pump near the irrigation turnout is designed to deliver 1,000 gpm at 60-psi pressure at the pump discharge. The filtration system consists of a sand media filter and screen filters.

The buried PVC mainline for the surface drip system is installed across one end of the field and supplies four separate buried PVC submains that run the length of the field. The lateral distribution lines consist of above-ground polyethylene drip tube, which is assumed to be spaced at 18-foot intervals along the submain. The plug-in drip emitters are assumed to be installed approximately every 21 feet along the laterals. This design is representative of that used for a permanent tree crop, such as almonds, but a similar system for vines would require nearly the same amount of material (e.g. fewer emitters per plant but plants closer together). Micro-spray systems are another technology that is seeing rapid growth in acreage. However, consultation with suppliers and installers of surface drip systems resulted in approximately the same cost per acre for a micro-spray system as for a surface drip system. Therefore, the surface drip system was retained to represent all "micro-application" surface systems.

Technology in subsurface drip systems is progressing rapidly. Currently, systems are being field tested that will remain as permanent systems for up to 10 years. This is unlike early buried drip-tape systems that required replacement of tape every few years and supplied water through an aluminum mainline (that required removal prior to all cultivation or harvest procedures). Systems now are being placed completely underground using PVC mainlines and submains and running laterals with in-line turbulent flow emitters. However, because these latest systems are in limited use compared to earlier systems, the original subsurface system was retained (Gohring, 1991). Minor modifications were made to reflect current pricing for materials and installation and to increase the life of the drip tubing (to 5 years from 3 years). Consultation with suppliers and installers of subsurface drip systems showed prices for a more permanent system (as discussed above), though more expensive initially, is nearly the same on an annual basis as the system used in this study.

The original design consists of an above-ground aluminum mainline installed across one end of the field supplying three separate above-ground aluminum submains that run the length of the field. The lateral distribution lines consist of bi-wall drip tube which is buried 8 to 10 inches below each bed on 60-inch centers (new systems are burying tubing approximately 18 inches below ground). In-line emitters are assumed to be spaced every 12 to 18 inches. Subsurface drip systems have been used in California on strawberries, tomatoes and peppers. In field trials, subsurface drip has been used on cotton, wheat, lettuce, and tomatoes (Phene, 1993).

2.7 Linear-move Sprinkler System

A linear-move sprinkler system uses a traveling pipeline that is suspended approximately 10 feet above ground on small motorized tractor units. The water is distributed to the field by sprinklers, typically mounted on spray booms, attached to the elevated pipe. The traveling pipeline is typically fed by a traveling pump station that draws water from an open ditch.

Linear-moves are used on a limited basis in some areas of the Central Valley. Proper system operation is critical to successful adaptation. If travel speeds are too slow, the moisture deficiency of crops may become too great between irrigations. Slow travel speeds on certain soils can also cause the small tractor units to become stuck. When travel speeds are too fast, the crops may receive more damage from saline water (due to frequent occurrence of salts on crop foliage), and energy costs will increase (from increased number of trips).

Apparently, because of complexities in operating and maintaining linear-moves and high initial capital cost, this technology has not been widely adapted to the Central Valley. A comparison of a linear-move system with a furrow irrigation system in Arizona cotton fields indicated that yield increase were essential for the profitability of the linear-move system (Wilson et al., 1987). Water and labor savings did not generate enough cash to pay for the new system. Wilson also stated that it may take two to four years to achieve a sustainable yield increase because of the need to learn how to operate the linear-move and calibrate its water and fertilizer application rates. The representative linear-move system consists of a 1-mile-long concrete-lined supply ditch and typical half-mile-long, center-fed linear-move system.

2.8 Low Energy Precision Application (LEPA) Systems

LEPA is an emerging technological advancement of the traditional linear-move or center-pivot irrigation system. It has been developed in the rolling hills of west Texas and has been primarily used in Texas, Colorado, and Kansas, where water supplies are limited and pumping costs are relatively high. LEPA makes use of two major modifications to the linear-move system (center pivots were not considered for this study). The first modification is that all sprinklers are replaced by drop tubes and bubbler heads equipped with energy dissipation covers. Waterflow is directed into the furrow. Second, in sloping areas, soil dikes are formed along the furrow to restrict flow of the applied water.

Each bubbler delivers water at a rate of about 7 gpm. The pressure required along the main lateral for LEPA is 10 to 15 psi versus 60 to 80 psi for a standard linear-move system. The representative LEPA system consists of a 1-mile-long concrete-lined supply ditch and a typical half-mile-long, center-fed linear-move system.

2.9 Solid Set Systems

Because of the wide use of solid set sprinkler systems for tree and vine crops, this technology was added to those evaluated during the original technical memorandum (Gohring, 1991). Systems typically include PVC mainline, submains, and laterals buried approximately 3 feet underground. Sprinklers rise from the laterals and either are placed between trees (in-row) or are attached to stakes and rise above the permanent crop canopy (e.g.; vines and apples). For this evaluation, a typical system was not designed, instead an average price per acre for an installed system was received from suppliers and installers and placed into the evaluation.

2.10 Tailwater Recovery Systems

The tailwater recovery system is used to carry runoff water to the head of the field to be reapplied. The system components include a sump, pumping plant, and return pipeline.

This study assumes that the return pipeline is 1/2-mile long so that runoff can be reapplied to any part of the field.

Section 3
Performance Characterizations

(**Note to reader:** This update of the original technical memorandum (Gohring, 1991) did not attempt to make any adjustments to the performance characteristics of the original irrigation technologies evaluated. Estimates of performance characteristics were made for the addition of rice irrigation methods and solid-set sprinkler systems.)

To facilitate hydrologic modeling, each of the 14 previously described irrigation systems (and 3 rice irrigation systems) is characterized with respect to its hydraulic performance. These characterizations consist of fractions that specify the distribution of applied water to each of the following four uses and losses.

- Consumptive Use (CU)--Consists of crop evapotranspiration
- Deep Percolation Loss (DP)--Consists of water percolating below the root zone
- Uncollected Runoff Loss (UR)--Consists of tailwater that is not collected for reuse
- Evaporation Loss (EL)--Consists of evaporation from head and tail ditches, from droplets as they travel through the air from sprinkler nozzles to the ground surface, from wetted soil surfaces, and from basins used in rice production.

The four distribution fractions always total to exactly one to account for all applied water (see Table 3.1). Leaching requirements are included in the DP fraction; it is not included as CU for purposes of this study.

Irrigation system performance evaluations conducted in Westlands Water District during the 1987-88 irrigation season (October 1987 through September 1988) are the principal basis for the characterizations (SJVDP, 1988). That survey included evaluation of one preseason and at least one growing season irrigation event on more than 200 individual fields, facilitating a seasonal representation of irrigation application efficiency. To be consistent with the Westlands survey, the characterizations presented here also represent seasonal performance or application efficiencies. For rice production, conversations with industry representatives provided information to estimate rice system characteristics (Boyle, 1994; Williams, 1994).

Relative to other parts of the Central Valley, the Westlands data were considered to represent a good, or medium, level of irrigation management. The Westlands data, in combination with other information sources, were adjusted to represent the low and high management levels previously described. The high management level is intended to represent the best seasonal application efficiency potentially achievable with each system.

Table 3.1
Distribution Fractions

Technology	Management Level	C~~B~~U (%)	DP (%)	UR (%)	EL (%)
F2	Low	45	39	15	1
	Medium	64	32	3	1
	High	70	26	3	1
F2-R	Low	52	46	1	1
	Medium	71	28	0	1
	High	76	23	0	1
F4	Low	49	32	18	1
	Medium	67	29	3	1
	High	72	24	3	1
F4-R	Low	58	38	3	1
	Medium	74	23	2	1
	High	82	17	0	1
BORD	Low	45	39	15	1
	Medium	66	30	3	1
	High	80	16	3	1
BORD-R	Low	56	40	3	1
	Medium	73	24	2	1
	High	85	14	0	1
RICE-C	Flow-through	52	23	20	5
	Recirculating	57	23	15	5
	Static	60	23	12	5
SURG-2	Low	58	40	1	1
	Medium	74	24	1	1
	High	79	19	1	1
SURG-4	Low	62	34	3	1
	Medium	78	19	2	1
	High	87	12	0	1
HMS	Low	51	35	5	9
	Medium	66	27	1	6
	High	77	18	1	4
DRIP	Low	62	38	0	0
	Medium	74	26	0	0
	High	90	10	0	0
SUB-DRIP	Low	62	38	0	0
	Medium	74	26	0	0
	High	90	10	0	0
LINEAR	Low	63	20	8	9
	Medium	80	13	1	6
	High	86	10	0	4
LEPA	Low	68	19	12	1
	Medium	83	12	4	1
	High	89	9	1	1
SOLID SET	Low	63	23	5	9
	Medium	77	16	1	6
	High	82	13	1	4

3.1 Furrow Systems

For all four furrow categories, the distribution fractions used for medium and high management furrows are based on those presented by the SJVDP (1988) for average and good management levels.

For half-mile furrows under medium management, the BU fraction is 3 percent less, and the DP fraction is 3 percent more than the values presented by the SJVDP (1988) to create a greater relative difference between the half- and quarter-mile furrows. For the quarter-mile furrows, the values used for medium and high management levels are those presented by the SJVDP (1988).

The low management distribution fractions were obtained by considering the effects of management on deep percolation and uncollected runoff fractions.

It is estimated that low management practices will increase deep percolation 20 to 25 percent. The increase in the DP fraction is estimated to be greater for the half-mile furrows since differences in intake opportunity times will be greater.

The uncollected runoff fraction is estimated to decrease a small amount for furrows with tailwater recovery systems. For systems without return flow systems, the increase in UR is estimated to be between 10 and 15 percent. The increase is estimated to be slightly greater for the quarter-mile furrows since runoff amounts have a potential for being higher with shorter advance distances.

For all surface systems, the evaporation losses are estimated to remain at 1 percent regardless of management level.

3.2 Border Strip Systems

Border strip irrigation is similar to furrow irrigation in that water is delivered to the upstream end of the field, and the soil surface is used to convey the water across the field. For this reason, the uncollected runoff and evaporation losses for border strip are assumed to be the same as for furrows.

Borders have a slightly higher potential for deep percolation because water must travel transversely across the field as well as laterally. This added flow dimension will increase the difference in intake opportunity time, which influences deep percolation. It is estimated that DP will be 1 to 3 percent higher for border strips than for furrows. This increase will be greater for low management than for medium and high management levels.

3.3 Rice Systems

The three rice irrigation systems described previously are fairly similar in their distribution fractions. This is because of the water management requirements and growing conditions for rice production.

First, because rice is grown in flooded basins, the potential for deep percolation is great. The limiting factor is the soil type which is fairly consistent under all rice fields (Williams, 1994). The high average deep percolation through clay rice soils is 23 percent (approximately 1.25 to 1.5 feet/year). The second common factor is evaporation. Because the basins are constantly flooded with water, the potential for evaporation is greater than with other surface irrigation systems. Typically, 5 percent of the applied water is lost to evaporation. The third common factor results from cultural practices toward the end of the growing season when rice fields are drained. Approximately 6 inches of applied water, roughly 12 percent, are typically drained (Williams, 1994).

Because consumptive use of rice is constant for various system types, the only variation can occur through additional spillage beyond what is lost during drainage. The static system has the least potential for additional spillage and therefore has a resulting BU fraction estimated at 60 percent. The recirculating system and conventional flow-through systems have increasing potential for spillage, and were estimated to have BU fractions of 57 and 52 percent, respectively.

3.4 Surge Control Furrow Systems

Under medium and high management, it is estimated that the evaporation will be the same as that for standard furrows. Uncollected runoff fractions are estimated to be greatly reduced for 1/2-mile surge systems as compared to standard furrows. 1/4-Mile surge systems will have UR fractions similar to their 1/4-mile furrow with return system counterpart. This assumption is based on studies showing that surge flow can reduce differences in intake opportunity time thus reducing potential UR.

Growers in the San Joaquin Valley have indicated that surge flow irrigation yields significant benefits (Taylor, 1987; Wooley, 1987). These benefits include a reduction in differences in intake opportunity time between upstream and downstream ends of the field, a decrease in water use, and a decrease in total advance time.

Charles Burt (1988) has estimated that the maximum potential BU of surge control irrigation is approximately 85 percent, and that a BU of 80 percent is currently being achieved by some growers in the San Joaquin Valley.

A BU fraction of 87 percent is estimated for quarter-mile surge systems operated under a high level of management. A similar relationship is assumed to exist between the BU fractions for surge flow systems and those of conventional furrows: BU is approximately 4 percent lower for half-mile furrows than for quarter-mile furrows under the same level of management, and BU under the medium management level is approximately 5 to 7 percent lower than for high management.

3.5 Hand-move Sprinkler Systems

The distribution fractions for hand-move sprinklers under medium management are assumed to be those given by the SJVDP (1988) for average management. For high management, it was estimated that the use of alternate sets and proper system pressures would result in a BU fraction of 77 percent, slightly higher than that reported by the SJVDP (1988). For low management, it is estimated that deep percolation increases approximately 8 percent. It is assumed that as management level decreases, the runoff will increase significantly. This consequence is likely to occur when set times are too long, adequate pressures are not maintained, too many laterals are operated at once, or leaking pipes or poorly operating sprinklers are not repaired or replaced.

The UR fraction is estimated to be approximately 4 percent higher for low management levels than for medium levels. Jensen (1984) has reported that evaporation losses are seldom higher than 9 percent of the applied water for sprinkler irrigation systems.

The resulting BU fraction for low management is approximately 15 percent lower than for high management levels.

3.6 Surface Drip Systems

Runoff and evaporation losses for drip systems are usually negligible. For this reason, the UR and EL fractions for all management levels are estimated to be zero.

The BU fractions reported for drip irrigation by the SJVDP (1988) were adjusted upward by 4 to 6 percentage points to reflect the benefit of potentially high application uniformities associated with the method.

If not properly managed, drip emitters can become clogged, which drastically decreases uniformity. Nakayama and Bucks (1979) have reported that having 20 percent of the emitters plugged can result in an application uniformity of approximately 50 percent. However, considering recent advances in filtration technology and clogging prevention, the BU fraction under low management was reduced to only 62 percent.

3.7 Subsurface Drip Systems

Recent advances appear to have been made in subsurface drip tubing and in-line emitters by creating a turbulent flow regime that minimizes clogging. However, because these improvements have not been well documented in production agriculture, surface drip performance characteristics were used to represent subsurface drip systems.

3.8 Linear-move Sprinkler System

Linear-move sprinkler systems, when operated correctly, have a high potential for uniform water application (USDA-SCS, 1983). The SJVDP (1988) has indicated that linear-move systems can obtain beneficial use fractions of 75 to 85 percent.

Runoff and evaporation losses of linear-moves are estimated to be similar to those of hand-move sprinklers, because both irrigation methods use aerial spraying for applying water to the field. However, the UR fraction was increased from 5 to 8 percent under the low management level to reflect the relatively high runoff that can result from high application rates typical of linear-move systems.

Under low management, the BU fraction was estimated to be 63 percent to reflect the relatively high distribution uniformities typical of moving lateral systems, compared to stationary systems such as hand-move sprinklers.

For medium management, the BU fraction is estimated to be the average of those reported by the SJVDP (1988). The BU of linear-moves was described as being 75 to 85 percent; thus, the BU fraction is estimated to be 80 percent for the medium management level.

For the high management level, the BU is estimated to be 86 percent. This is based on information gathered by Burt (1988) in which he noted that linear systems often are operated at 85 percent efficiency and can be operated at 90 percent.

3.9 LEPA Systems

LEPA systems are designed to be more efficient than a linear-move system. Evaporation losses are reduced by dropping the water directly into the furrow. Therefore, the EL fraction was estimated to resemble furrow irrigation at 1 percent for all levels of management.

Runoff under LEPA can be high because the application rate is usually higher than the soil intake rate and because of sloping terrain. Under low management, the UR is similar to furrow systems and is estimated to be 12 percent. However, when these situations occur, dikes are made across the furrows to hold the water back. Thus, under high management, the UR is estimated to be 1 percent.

The DP fraction for low and medium management levels is estimated to be slightly better than a linear system at 19 and 12 percent, respectively. However, for the high management level, Vlotman and Fangmeier (1983) reported irrigation efficiencies of 88 to 96 percent. For this reason, a BU fraction of 89 percent was used for a high level of management.

3.10 Solid Set Sprinkler Systems

The distribution fractions for solid set sprinkler systems are estimated to fall between efficiencies shown for hand-move sprinkler systems and linear-move systems.

Runoff and evaporation losses are estimated to be similar to those of hand-move sprinklers, because both irrigation methods use aerial spraying for applying water to the field. Deep percolation factors were reduced from those of hand-move sprinklers for low management levels because these systems are designed as turnkey systems. This allows for greater set control, fewer damaged parts, and better system designs to provide more uniform application efficiencies. Lower deep percolation fractions occur under the medium and high management levels also.

The BU fraction for high management was below that of linear-move yet greater than achievable through hand-move systems. This is a result of the higher deep percolation fraction than that of linear-move as stated above.

Section 4
Crops

A wide variety of crops is grown in the Central Valley. The costs, water use, and yields of a given crop may vary with soil type, topography, management intensity, planting and harvesting date, or other cultural practices.

For the purpose of this study, crops have been characterized by the following categories:

- ALF - Alfalfa Hay
- TFN - Trees and Vines
- ROW - Row crops (primarily cotton)
- GRN - Grain
- VEG - Vegetable and truck crops
- TOM - Tomatoes
- SBT - Sugar Beets
- RICE - Rice (primarily white varieties grown in Sacramento Valley)

It is recognized that some crops may not clearly be represented by these categories, but these groups represent the vast majority of crops grown in the Central Valley.

Section 5
System Costs

Costs of purchase and operation were prepared for each system. The following sections describe the costs for capital investment, system maintenance, pumping, labor, and management. Some combinations of systems and crops are excluded due to incompatibility between irrigation operations and cultural activities.

5.1 Capital Costs

(**Note to reader:** Suppliers were not re-contacted regarding original estimates of system capital costs. Where costs were questionable (e.g.; for surface and subsurface systems) or where new costs needed to be developed (e.g.; solid-set sprinklers) the same or new suppliers were contacted regarding current pricing. Because of the inherent inconsistency in presenting the individual cost data from two studies, presentation of costs by information source are not included. Instead, only the estimate column is shown.)

Costs of purchasing and installing the irrigation systems described above were computed by compiling costs from various sources. To obtain system component costs, irrigation retailers were asked for realistic price data for the components when purchased in quantities required for the systems (with the exception of solid set sprinkler systems which were estimated on a per acre basis). Data sources are listed in Appendix B.

Annual costs were determined by amortizing each component over its estimated useful life (Tables 5.1a through 5.1o). Assuming farmer initiated loans, an 8.0 percent interest rate was used for all calculations.

5.2 Maintenance Costs

Maintenance costs are required to keep the irrigation equipment in working condition. The management level will significantly affect the maintenance cost. Maintenance cost can be estimated as a percentage of the total capital cost of the irrigation system (Jensen, 1984).

5.2.1 Surface Systems

Maintenance costs for surface systems are divided into three categories: delivery, land grading, and return system. The maintenance costs for the delivery system are based on the percentages of the capital costs of the components. The land grading is assumed constant for a particular-size field and management level. The maintenance costs of the return system are similar to those for the water delivery system.

Table 5.1a Component Costs for 1/2-Mile Furrows (Low Management)						
Item	**Qty.**	**Unit**	**Life (years)**	**Estimate ($)**	**Subtotal Cost ($)**	**Annual Cost ($)**
Head Ditch *	2,640	Ft/yr	1	0.10	1,771.46	264.00
1-1/2 inch siphon tubes	110	Each	5	4.50	495.00	123.98
				Total =	2,266.46	388.03
				Initial Invest. ($/ac) =	14.17	
				Unit Cost ($/ac/yr) =		2.43
* Cost shown is annual cost of installing head ditch. Subtotal cost is present value of installation cost over a 10-year period						

Table 5.1b Component Costs for 1/2-Mile Furrows (Medium and High Management)						
Item	**Qty.**	**Unit**	**Life (years)**	**Estimate ($)**	**Subtotal Cost ($)**	**Annual Cost ($)**
10-inch Gated Pipe	2,640	FT	8	4.33	11,431.20	1,989.20
				Total =	11,431.20	1,989.20
				Initial Invest. ($/ac) =	71.45	
				Unit Cost ($/ac/yr) =		12.43

Table 5.1c Component Costs for 1/4-Mile Furrows (Low Management)						
Item	**Qty.**	**Unit**	**Life (years)**	**Estimate ($)**	**Subtotal Cost ($)**	**Annual Cost ($)**
Head Ditch *	6,600	FT/YR	1	0.10	4,428.65	660.00
1-1/2 inch siphon tubes	220	EA	5	4.50	990.00	247.95
				Total =	5,418.65	907.95
				Initial Invest. ($/ac) =	33.87	
				Unit Cost ($/ac/yr) =		5.67
* Cost shown is annual cost of installing head ditch. Subtotal cost is present value of installation cost over a 10-year period						

Table 5.1d Component Costs for 1/4-Mile Furrows (Medium and High Management)						
Item	**Qty.**	**Unit**	**Life (years)**	**Estimate ($)**	**Subtotal Cost ($)**	**Annual Cost ($)**
10-inch Gated Pipe	5,280	Ft.	8	4.33	22,862.40	3,978.40
10-inch Plain Pipe	1,320	Ft.	8	3.73	4,923.60	856.78
Misc. Fittings	1	Each	8	450.00	450.00	78.31
10-inch Butterfly Valve	2	Each	10	156.00	312.00	46.50
				Total =	28,548.00	4,959.98
				Initial Invest. ($/ac) =	178.43	
				Unit Cost ($/ac/yr) =		31.00

Table 5.1e
Component Costs for 1/2-Mile Border Strips (Low Management)

Item	Qty.	Unit	Life (years)	Estimate ($)	Subtotal Cost ($)	Annual Cost ($)
Head Ditch	2,640	Ft/yr	1	0.10	1,771.46	264.00
4"x72" Siphon Tubes	22	Each	5	30.00	660.00	165.30
				Total =	2,431.46	429.30
				Initial Invest. ($/ac) =	15.20	
				Unit Cost ($/ac/yr) =		2.68

* Cost shown is annual cost of installing head ditch. Subtotal cost is present value of installation cost over a 10-year period

Table 5.1f
Component Costs for 1/2-Mile Border Strips (Medium and High Management)

Item	Qty.	Unit	Life (years)	Estimate ($)	Subtotal Cost ($)	Annual Cost ($)
15-in Low head PVC pipe	6,600	Ft.	10	5.60	36,960.00	5.508.13
12-in Alfalfa valve w/ riser and saddle	130	Each	10	122.00	15,860.00	2,363.61
Misc. Fittings and Vents	1	Each	10	650.00	650.00	96.87
14-in Butterfly Valve	2	.Each	10	760.00	1,520.00	226.52
Pipe Installation:						
15-in Low head PVC pipe	6,600	Ft.	10	1.25	8,250.00	1.229.49
				Total =	63,240.00	9.424.62
				Initial Invest. ($/ac) =	395.25	
				Unit Cost ($/ac/yr) =		58.90

Table 5.1g
Component Costs for Rice Systems

Item	Qty.	Unit	Life (years)	Estimate ($)	Subtotal Cost ($)	Annual Cost ($)
Conv. Flow-through *	160	AC	2	4.40	704.00	352.00
				Total =	704.00	352.00
				Initial Invest. ($/ac) =	4.40	
				Unit Cost ($/ac/yr) =		2.20
Recirculating System *	160	AC	15	108.00	17,280.00	1.152.00
				Total =	17,280.00	1,152.00
				Initial Invest. ($/ac) =	108.00	
				Unit Cost ($/ac/yr) =		7.20
Static System *	160	AC	10	70.00	11,200.00	1,120.00
				Total =	11,200.00	1,120.00
				Initial Invest. ($/ac) =	70.00	
				Unit Cost ($/ac/yr) =		7.00

* System costs are based from USDA SCS report (Boyle, 1994)

Table 5.1h Component Costs for 1/2-Mile Surge-Controlled Furrows						
Item	**Qty.**	**Unit**	**Life (years)**	**Estimate ($)**	**Subtotal Cost ($)**	**Annual Cost ($)**
10-inch Gated Pipe	2,640	.Ft.	8	4.33	11,431.20	1,989.20
10-inch Plain Pipe	1,320	Ft.	8	3.73	4,923.60	856.78
Misc. Fittings	1	Each	8	450.00	450.00	78.31
10-inch Surge Valve	1	Each	8	1,672.00	1,672.00	290.95
				Total =	18,476.80	3,215.24
				Initial Invest. ($/ac) =	115.48	
				Unit Cost ($/ac/yr) =		20.10

Table 5.1i Component Costs for 1/4-Mile Surge-Controlled Furrows						
Item	**Qty.**	**Unit**	**Life (years)**	**Estimate ($)**	**Subtotal Cost ($)**	**Annual Cost ($)**
10-inch Gated Pipe	5,280	Ft.	8	4.33	22,862.40	3,978.40
10-inch Plain Pipe	1,320	Ft.	8	3.73	4,923.60	856.78
Misc. Fittings	2	Each	8	450.00	900.00	156.61
10-inch Butterfly Valve	2	Each	10	156.00	312.00	46.50
10-inch Surge Valve	1	Each	8	1,672.00	1,672.00	290.95
				Total =	30,670.00	5,329.24
				Initial Invest. ($/ac) =	191.69	
				Unit Cost ($/ac/yr) =		33.31

Table 5.1j Component Costs for Hand-Move Sprinklers Pump Q = 1,600 gpm Pump H = 80 psi						
Item	**Qty.**	**Unit**	**Life (years)**	**Estimate ($)**	**Subtotal Cost ($)**	**Annual Cost ($)**
12"x45' Al. M.L. w/valve	13	Each	10	251.00	3,263.00	486.28
12"x45' Al. M.L. w/o valve	66	Each	10	216.00	14,256.00	2,124.56
10"x45' Al. M.L. w/valve	18	Each	10	189.00	3,402.00	507.00
10"x45' Al. M.L. w/o valve	18	Each	10	156.00	2,808.00	418.47
8"x45' Al. M.L. w/valve	9	Each	10	155.00	1,395.00	207.90
8"x45' Al. M.L. w/o valve	9	Each	10	128.00	1,152.00	171.68
6"x45' Al. M.L. w/valve	13	Each	10	115.00	1,495.00	222.80
6"x45' Al. M.L. w/o valve	13	Each	10	89.00	1,157.00	172.43
4"x30' Al. Lateral	530	Each	8	41.00	21,730.00	3,781.34
R.B. 29JH w/nozzle	530	Each	4	6.22	3,296.60	995.31
24-inch riser	530	Each	8	1.43	757.90	131.89
Valve Opening Elbows	12	Each	8	50.00	600.00	104.41
100-hp Pump Purchase	1	Each	20	7,000.00	7,000.00	712.97
				Total =	62,312.50	10,037.04
				Initial Invest. ($/ac) =	389.45	
				Unit Cost ($/ac/yr) =		62.73